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EVALUATING THE PERFORMANCE OF MASS RAPID TRANSIT STATIONS BY THE DEA MODEL- A STUDY OF ZHONGHE-XINLU LINE

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ABSTRACT

The MRT system that features high efficiency, energy saving and cleanliness becomes favorable in the recent year for emphasizing on sustainable development. However, the performance of MRT system is attended normally because of its bulky construction cost. Among the performances of MRT system, the decision on the location/position and the number of MRT stations influences the most.

In the past, the domestic studies on the performance of MRT system mostly focused on the road network and operation of MRT, and paid less attention to MRT station. Moreover, the performance evaluation mostly starts from MRT administration view, and is less attentive to the benefits of users. Besides, there has no operable evaluation efficiency framework of MRT station to provide for reference. Thus, this paper establishes operable evaluation efficiency framework for MRT station, and through the empirical analysis of 26 MRT stations in Zhonghe-Xinlu Line by DEA, to expect the outcome of analysis to be regarded as references for the MRT development and policy in the future.

According to the outcome of empirical analysis in this paper, Jingan station and Yongan Market station are relatively efficient and achieve optimal scale level. Jingan station shows the strongest steadiness in efficiency because of having the largest number of references by inefficient DMUs. Based on the result of Slack Variable Analysis, Danfeng station is the most necessary improvement among all MRT stations in Zhonghe-Xinlu Line.

KEYWORDS: MRT Station, Efficiency Analysis, Data Envelopment Analysis

INTRODUCTION

Facing the sustainable development, most cities in the world has taken public transport system as the core of transport development, and Mass Rapid Transit (MRT) system is one of the key elements of it [1].However, the Performance of MRT system is attended normally because of its bulky construction cost. Among the performances of MRT system, the decision on the location/position and the number of MRT stations influences the most. That is, the operating performance of MRT system will be enhanced if the decision of MRT stations is well, or, will be reduced if not.

The studies on the performance of MRT system in the past mostly focused on the road network and operation of MRT, and paid less attention to MRT station. Moreover, the performance evaluation mostly starts from MRT administration view, and is less attentive to the benefits of users [2, 3, 4]. Besides, there has no operable evaluation efficiency framework of MRT station to provide for reference.

Taipei MRT is the largest MRT system in Taiwan. Although the Taipei MRT system has developed five major transit routes (including 12 sub-routes) and 107 MRT stations, it often has suffered controversy and criticism on the decision of MRT stations. Moreover, the MRT stations in Zhonghe-Xinlu Line which had operated recently are suffered

more serious controversy. Thus, this paper establishes operable evaluation efficiency framework for MRT station, and through the empirical analysis of 26 MRT stations in Zhonghe-Xinlu Line by DEA, to expect the outcome of analysis to be regarded as references for the MRT development and policy in the future.

The paper is divided into 5 parts. The research motive and purpose, contents and previous research outcomes stated in this paragraph. The efficiency evaluation framework, indicators, evaluation method and model of MRT station in the methodology stated in the second paragraph. The description of the empirical sample proceeded in the third paragraph. This paper followed by empirical analysis on the efficiency of MRT in Zhonghe-Xinlu Line with the related suggestions for improvement proposed via DEA in the fourth paragraph. The conclusions and suggestions proposed lastly.

METHODOLOGY

The Efficiency Evaluation Framework of MRT Station

Because the past studies lacked of operational evaluation framework, this study proposes the evaluation framework, and shows as Figure 1. In addition to an analytical framework for this paper, it also can apply to the evaluation of MRT stations in the different regions and countries due to its general rule.

The contents of various steps in this evaluation framework include: 1. Confirmation of decision making unit (DMU): select MRT station that expects to be evaluated; 2. Selection of input output indicator: proceed related data gathering and evaluation of the input indicators that reflect the construction cost of MRT station and the output indicators that reflect the transportation benefit of MRT station; 3. Efficiency evaluation of MRT stations: evaluate the efficiency of MRT stations in Zhonghe-Xinlu Line through Efficiency Analysis, Reference Set Analysis and Slack Variable Analysis; 4. Selection of efficient MRT stations: generate and choose the efficient MRT stations through the efficiency evaluation; 5. Suggestions on policy : draw up corresponding suggestions for policy improvement and management strategies.

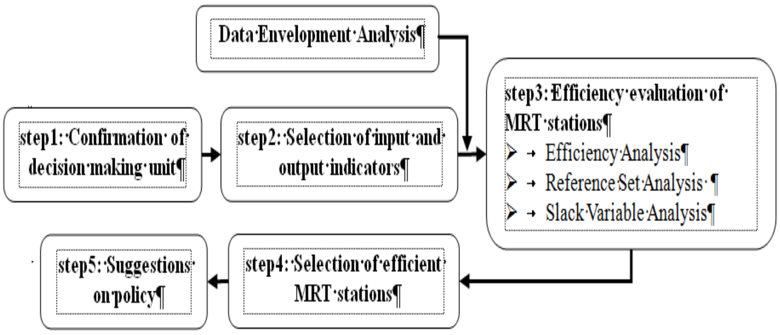

Figure 1: Efficiency Evaluation Framework of MRT Stations

Decision Making Unit

Based on considering data consistency and analysis accuracy, 26 MRT stations in Zhonghe-Xinlu Line were derived and considered as DMUs in the efficiency evaluation of MRT stations. Moreover, the quantity of DMUs in this study conforms to the experience rule determined by the amount of DMUs of DEA, i.e., the number of evaluated DMUs shall be more than double of total input and output indicators numbers to avoid excessive evaluated units to fall on the efficiency frontier and lose discrimination of DEA.

EFFICIENCY EVALUATION METHOD AND MODEL

Efficiency Evaluation Method

DEA is a non-parametric efficiency frontier analytical method which can be used to evaluate the relative efficiency of multiple inputs and multiple outputs DMUs. Moreover, the analysis by DEA does not preset any function between input indicator and output indicator. The method realistically uses observable data to choose input and output indicators, and uses mathematics programming to establish a production frontier which is relatively efficient the most. The efficiency value of DMUs located on the production frontier all report 1, and at the same time, this DMU has become the face reference set of inefficient DMUs. Those inefficient DMUs will be located underneath the production frontier and will be rendered with an efficiency value between 0 to 1 upon its distribution status. In addition, the Reference Set Analysis of DEA can discriminate level of efficiency of DMUs and further distinguish level of efficiency steadiness of efficient DMUs. The Slack Variable Analysis of DEA can provide the improved information for the inefficient DMUs, and make the inefficient DMUs to achieve the efficiency level by increasing inputs or decreasing outputs.

Efficiency Evaluation Model

There are many models in DEA, including CCR model, BCC model, additive model, multiplicative model, window analysis, malmquist index, etc. [5]. This paper is intended to deal with cross-section efficiency of MRT stations. Therefore, takes the CCR model and BCC model as efficiency evaluation model. The CCR model was established by Charnes et al. [6], and the BCC model was established by Banker et al. [7], those formulas and equations can be consult in research above [5, 6, 7]. Moreover, DEA has developed many corresponding models upon different situations, however, the common part between these models is guidance issue, i.e. most of the DEA models can be divided into input oriented and output oriented models. The former is to derive minimum possible proper input volume under current production, and the latter is to derive maximum possible output volume under current input. In this study, output oriented is used to calculate the DEA models (such as CCR and BCC models) because of input indicators (such as MRT construction cost) being fixed. That is, this study is to maximum possible output under the fixed input number by output oriented.

Efficiency Evaluation Indicators

In order to effectively and completely proceed efficiency analysis of MRT station, the paper has referred to related research outcomes[1, 8, 9, 10], and chooses the 6 variables (such as “MRT construction cost”, “passenger volume”, “comfort of MRT station”, “accessibility of MRT station”, “esthetics of MRT station”, “convenience of MRT station”) for the efficiency measurement of input and output indicators respectively under the limitation of acquired data, in which the meaning, contents, code and evaluation units are consolidated as Table 1.

Table 1: The List of Measurement Variables

Perspective	Variables	Code	Content of Variable	Unit
Input Indicators	MRT construction cost	CC	average construction cost of each MRT station	million(TWD)
Output Indicators	passenger volume	PV	passenger volume of each MRT station	person
	comfort of MRT station	CM	feel the level of comfort for MRT station	score
	accessibility of MRT station	AM	feel the level of accessibility for MRT station	score
	esthetics of MRT station	EM	feel the level of esthetics for MRT station	score
	convenience of MRT station	VM	feel the level of convenience for MRT station	score

Data

Based on considering data consistency and analysis accuracy, 26 MRT stations in Zhonghe-Xinlu Line (including Zhonghe Line, Xinzhuang Line and Luzhou Line) were derived as the spatial scope of empirical analysis. The 26 MRT stations include Dingxi, Songjiang Nanjing, Jingan, Yongan Market, Xingtian Temple, Fu Jen University, Dongmen, Minquan West Road, Guting, Zhongxiao Xinsheng, Nanshijiao, Zhongshan Elementary School, St. Ignatius High School, Sanmin Senior High School, Luzhou, Sanchong Elementary School, Sanhe Junior High School, Daqiaotou, Xinzhuang, Taipei Bridge, Cailiao, Touqianzhuang, Huilong, Sanchong, Xianse Temple, and Danfeng stations.

As for data type, all variables are quantifiable. The source of data gathering, except “MRT construction cost” and “passenger volume” gathered secondary data by statistical database of Taipei City Government and New Taipei City Government, the rest variables are acquired from questionnaire which conducted by random interview.

EMPIRICAL ANALYSIS AND DISCUSSIONS

Efficiency Analysis

According to the efficiency evaluation outcomes of MRT stations by CCR model (Table 2), only 7.69％ of the MRT stations in Zhonghe-Xinlu Line has total technical efficiency, and the other MRT stations are inefficient. However, among of those inefficient MRT stations, 46.15％ of the MRT stations has high efficiency, and 23.08％ of the city/county in Taiwan has low efficiency.

Based on the outcome of efficiency analysis (Table 3), Jingan station and Yongan Market station report 1 efficiency value in the terms of total technical efficiency. Jingan station and Yongan Market station are the relatively efficient stations with considering optimal combinations of input and output variables by CCR model.

According to Table 3, Jingan station and Yongan Market station are not only the efficient cities of total technical efficiency, but also the efficient cities of pure technical efficiency and scale efficiency. However, if those inefficient cities/counties have pure technical efficiency (e.g. Zhongxiao Xinsheng station and Minquan West Road station), the inefficiency of cities/counties is resulted from scale inefficiency instead of technology inefficiency.

Moreover, as far as a return to scale is concerned, Jingan station and Yongan Market station achieve optimal scale level. Daqiaotou station, Songjiang Nanjing station, Dingxi station, Xinzhuang station report a status of increasing returns to scale, meaning that moderate expansion of scale is required to increase input volume to enhance overall efficiency. While the rest of MRT stations all report decreasing returns to scale, meaning that scale should be properly reduced to reduce input volume so as to enhance overall efficiency.

Table 2: Number and Ratio of Cities/Counties within the Range of Different Efficiency Value

Efficiency Level		Total Technical Efficiency		Pure Technical Efficiency		Scale Efficiency	
		Number	Ratio (%)	Number	Ratio (%)	Number	Ratio (%)
Range of efficiency value	1	2	7.69	4	15.38	2	7.69
	0.7-0.999	12	46.15	14	53.85	14	53.85
	0.4-0.699	6	23.08	4	15.39	7	26.92
	0-0.399	6	23.08	4	15.38	3	11.54
Total Amount		**26**	**100**	**26**	**100**	**26**	**100**

Table 3: Outcomes of Efficiency Analysis

Dmu	Total Technical Efficiency	Rank	Pure Technical Efficiency	Scale Efficiency	Number of References
Unit	-	-	-	-	Times
Jingan	1	1	1	1	23
Yongan Market	1	1	1	1	12
Zhongxiao Xinsheng	0.95	3	1	0.95	
Daqiaotou	0.93	4	0.94	0.99	
Minquan West Road	0.92	5	1	0.92	
Guting	0.91	6	0.95	0.96	
Songjiang Nanjing	0.90	7	0.95	0.95	
Zhongshan Elementary School	0.89	8	0.92	0.97	
Dingxi	0.87	9	0.96	0.91	
Dongmen	0.86	10	0.91	0.95	
Nanshijiao	0.84	11	0.92	0.91	
Xingtian Temple	0.79	12	0.91	0.87	
Touqianzhuang	0.76	13	0.86	0.88	
Xinzhuang	0.70	14	0.90	0.78	
Fu Jen University	0.54	15	0.80	0.68	
St. Ignatius High School	0.51	16	0.74	0.69	
Sanmin Senior High School	0.50	17	0.73	0.68	
Sanchong Elementary School	0.49	18	0.69	0.71	
Luzhou	0.48	19	0.71	0.68	
Sanhe Junior High School	0.47	20	0.67	0.70	
Sanchong	0.33	21	0.50	0.66	
Cailiao	0.31	22	0.48	0.65	
Taipei Bridge	0.16	23	0.36	0.44	
Huilong	0.13	24	0.34	0.38	
Xianse Temple	0.12	25	0.31	0.39	
Danfeng	0.11	26	0.33	0.33	

Reference Set Analysis

The Reference Set Analysis distinguish the steady level of efficient DMUs through calculating the times of those efficient DMUs regarded as object reference by the inefficient DMUs. The more a certain efficient DMU referred by other inefficient DMUs, the more steady the relative efficiency is. The study uses reference set analysis method expects to discriminate level of efficiency of DMUs and further distinguish level of efficiency steadiness of efficient DMUs, in addition to avoiding excessive efficient DMUs too more.

According to the outcome of reference set analysis (Table 3), Jingan station report the largest number of references for 23 times, and Yongan Market station report the number of references for 12 times. Therefore, comparing to other efficient MRT stations, Jingan station reports the strongest steadiness in efficiency.

Slack Variable Analysis

The Slack Variable Analysis helps understand the gap and room for improvement of DMU and efficiency target, which mainly uses the line segments of polyline to connect the various previous nodes to form an efficiency frontier, and to calculate the slack variables of various input and output items upon this efficiency frontier. It represents an excess of input

which to be reduced to attain efficiency level if the slack variable appears on the input item, or, represents an excess of undesirable output which to be reduced to attain efficiency level if the slack variable appears on the undesirable output item, or, represents insufficient desirable output which to be increased to achieve efficiency level if the slack variable appears on the desirable output item.

According to the outcome of Slack Variable Analysis(Table 4), the Danfeng station has poor performance in “passenger volume”, “comfort of MRT station”, “accessibility of MRT station”, “esthetics of MRT station”, “convenience of MRT station”, therefore, Danfeng station is the most necessary improvement among all MRT stations in Zhonghe-Xinlu Line.

Moreover, looking from level of improvement in various variables(Table 4), the Danfeng station reports the most necessary improvement in the variables of “passenger volume”, “comfort of MRT station”, “accessibility of MRT station”, “convenience of MRT station”, and the Xianse Temple station reports the most necessary improvement in the variables of “esthetics of MRT station”.

Table 4: Outcomes of Slack Variable Analysis Unit: %

Variables	PV	CM	AM	EM	VM
Last 2 DMUs (degree of improvement)	Danfeng (32.21%)	Danfeng (15.66%)	Danfeng (25.31%)	Xianse Temple (12.12%)	Danfeng (18.21%)
	Xianse Temple (28.42%)	Xianse Temple (13.52%)	Huilong (21.03%)	Danfeng (10.09%)	Huilong (16.32%)

CONCLUSIONS AND SUGGESTIONS

The MRT system that features high efficiency, energy saving and cleanliness becomes favorable in the recent year for emphasizing on sustainable development. However, the performance of MRT system is attended normally because of its bulky construction cost. Among the performances of MRT system, the decision on the MRT stations (such as location/position and amount of the MRT stations) influences the most.

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Finally, this paper only analyzed the efficiency of MRT stations in specific time and space by DEA model, because of limitation in data. Therefore, if sufficient data can be provided in the future, it can be analyzed and compared with each other for different time and space in the future study.

REFERENCES

1. Fouracre P, Dunkerley C, Gardner G. Mass rapid transit systems for cities in the developing world. *Transport Reviews*, 2003, 23(3): 299-310.
2. Benjamin J, Obeng K. The effect of policy and background variables on total factor productivity for public transit. *Transportation Research B: Methodological*, 1990, 24(1): 1-14.
3. Fielding Gordon J. Transit performance evaluation in the U.S.A. *Transportation Research A: Policy and Practice*, 1992, 26(6): 483-491.
4. Litman Todd. Impacts of rail transit on the performance of a transportation system. *Journal of the Transportation Research Board*, 2005, 1930: 23-29.
5. Cooper W W, Seiford L M, and Tone K. *Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References and DEA-Solver Software*, 2007, Boston: Springer-Verlag.
6. Charnes A, Cooper W W, Rhodes E. Measuring the efficiency of decision making units. *European Journal of Operational Research*, 1979, 3(4): 339-339.
7. Banker R D, Charnes A, Cooper W W. Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management Science*, 1984, 30(9): 1078-1092.
8. Black J A, Paez A, Suthanaya P A. Sustainable urban transportation: Performance indicators and some analytical approaches. *Journal of Urban Planning and Development*, 2002, 128(4): 184-209.
9. Haghshenas H, Vaziri M. Urban sustainable transportation indicators for global comparison. *Ecological Indicators*, 2012, 15(1): 115-121.
10. Shiau T A, Liu J S. Developing an indicator system for local governments to evaluate transport sustainability strategies. *Ecological Indicators*, 2013, 34: 361-371.